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Evaluation of Groundwater Suitability for Drinking and Irrigation Purposes in Toba Tek Singh District, Pakistan

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Abstract

Correlating the physicochemical parameters for assessment of the groundwater quality has emerged as a very useful approach for water use. Taking water samples from the Toba Tek Singh District of Pakistan, this study assess the water quality for drinking and irrigation purposes. A sum-total of 72nos. groundwater samples were collected and analyzed for the purpose of different water quality parameters including sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), pH, electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH). The results obtained were, then, compared with the standard desirable limits of physicochemical parameters prescribed by World Health Organization (WHO), Pakistan Standards and Quality Control Authority (PSQCA) and Pakistan Council of Research in Water Resources (PCRWR) for drinking purposes. In order to classify the groundwater suitability for irrigation purpose, parameters such as sodium adsorption ratio (SAR), percent sodium (PS), permeability index (PI), residual sodium bicarbonate (RSBC), Kelly's ratio (KR), and magnesium adsorption ratio (MAR) were also calculated on the basis of chemical data. After that, the correlation coefficients between different physicochemical parameters were calculated to identify the highly correlated and interrelated parameters for water quality. Different plots like Piper, Durov, Schoeller and Stiff diagrams were drawn to classify the groundwater ability for different purposes. These several classifications show most of groundwater samples falling within the safe limits and thus suitable for drinking and irrigation purposes, except of a few samples with a caution that it may get worse in the future.

Keywords: Physicochemical parameters; Correlation; WHO; Drinking; Irrigation; Pakistan

Introduction

Surface water and ground water are two main sources of water. Surface water includes rivers, canals, streams, fresh water lakes etc., while groundwater is obtained from well and borehole water [1]. Groundwater is under the earth surface originated as infiltration from precipitation, stream flows etc. Under the action of gravity the water moves downwards until it reaches strata to form the groundwater. About 97% of earth's fresh water is groundwater [2]. Groundwater is also an important part of the water cycle and is used to maintain soil moisture, wetlands, stream flow, and is also the main source of drinking and irrigation worldwide. Groundwater contains about 40 to 70% of the world water resources being used for drinking and irrigation purposes [3]. Due to decrease in surface water resources and partially pollution, the groundwater is becoming more important for drinking and irrigation purposes [4,5].

Water quality is very important for the suitability of groundwater for drinking and irrigation purposes. Water has ability to suspend, absorb and dissolve different compounds. By nature water is not pure as it gets contaminants from its surrounding caused by humans, animals and other biological actions [6,7]. Water seeps from the porous soil and gets dissolved salts and gases, metals, organic compounds, nitrates and sulphates [8-10]. Water contains the minerals useful for human nutrition [11]. The groundwater quality is one of the most important parts of water resource studies [12,13]. Scarcity of fresh water is one of most important environmental problems in the world today [14].

The groundwater quality depends on different processes starting from condensation in atmosphere to the water discharge from the well, and is controlled by dissolved salts, material type and disposal system. The water quality is deteriorated by both natural as well as anthropogenic factors [15]. The groundwater quality is controlled by contaminated activities, discharge recharge pattern and nature of the rocks [16]. The different contaminants present in the groundwater above the standard of World Health Organization (WHO) can cause different ailments in humans and are not safe for industrial uses [17,18]. The good quality water prevents disease and improves quality of life [19]. The distribution of trace elements in the groundwater has a large range of chemical composition [20]. This composition depends on aquifer lithology, quality of water recharge and human activities [21]. Univariate statistical analysis is applied to interpret the trace elements. Multivariate method can be used to explain the correlations between different variables [22,23]. This multivariate method is used widely to interpret relationships among different variables to manage the environmental system better [24,9].

The majority of people in developing countries use the water from shallow wells and boreholes which have high contaminations [25]. The pollution of groundwater aquifers causes the wells unfit for consumption [26]. Dramatic increase in world population has resulted in huge consumption of water resources [27]. The population explosion caused by the increase in urbanization, industrialization and development activities has produced the water crises [28]. Low water flow, industrial discharges and municipal effluents may cause the poor water quality [7]. The poor or bad water quality has its effects on life expectancy and the health; it is a constant hazard for soils and crops. Therefore, it is important to check the assessment and the estimation of the quality for ground water whether it is suitable for agricultural, domestic and industrial uses.

The water quality for irrigation and domestic uses is assessed by

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geochemical study [29-31]. Water quality is more important than water quantity in any drinking water supply planning [32,33]. Water quality standards are based on quality control program and treatment process. These standards are helpful for the identification of water quality problems caused by the discharge of waste water from active or abandoned mixing sites, fertilizers and sediments. These standards are very useful to assess the water quality conditions [34,35].

Generally, the water quality assessment is based on physicochemical analysis. World Health Organization (WHO) provides the guidelines for drinking water based on water quality parameters such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), pH, electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH). These parameters should be in permissible limits of concentration for drinking water quality [36,37]. If these parameters cross this limit, it may cause health diseases. Thus, the determination of concentrations of these parameters based on their guideline values is required for the assessment of suitability of drinking water [38].

The guideline for irrigation water quality is provided by the Food and Agriculture Organization (FAO) of the United Nations [39]. Salinity and sodium hazard indicators are useful to assess the suitability of irrigation water [40]. The sodium absorption ratio (SAR) is very effective assessment index for irrigation water [39,41,42].

Groundwater is the main source of drinking and irrigation water in Pakistan. The over burden population, unplanned urbanization, inappropriate dumping of solids and liquid wastes and loose governance have resulted in the deterioration of quality and quantity of groundwater in Pakistan [43]. The present study was carried out in Toba Tek Singh District of Pakistan to assess the groundwater quality for drinking and irrigation purposes. Groundwater is the main source of drinking and irrigation water in that area. The main goal of this study was to interpret the water quality by determining the variations in the physicochemical parameters, investigating the statistical, correlation and graphical analysis. In order to assess the irrigation water quality in the study area, different indices such as sodium adsorption ratio (SAR), percent sodium (PS), permeability index (PI), residual sodium bicarbonate (RSBC), Kelly's ratio (KR), magnesium adsorption ratio (MAR), total hardness (TH) were calculated from standard equations. It is anticipated that this study would be helpful to determine the water quality in District Toba Tek Singh, and to motivate further studies to this effect.

Study Area

Toba Tek Singh District is situated in Rechna Doab which is lying between Chenab River and Ravi River. It contains the latitude 30°33' to 31°2' N and the longitude 72°08' to 72°48' E (Figure 1). It is an important irrigation District of Southern Punjab in Pakistan. It has hot and dry climate in the summer season from April to October. The summer period is lengthy in the area. And May, June and July are the hottest months. During the summer season, 42°C and 29°C are mean maximum and minimum temperatures. The winter season is comparatively short. December, January and February are the coldest months. The mean maximum and minimum temperatures during the winter season are 29°C and 5°C, respectively. Monsoon is the rainy season in the district from July to September and most of the precipitation is during this season, but the rain in winter is scarce. The annual precipitation in the district is 158 mm.

Toba Tek Singh District is an alluvial plain where sand is the dominant subsurface lithology starting from some feet depth that formed good aquifers in the area. The drainage of the district depends

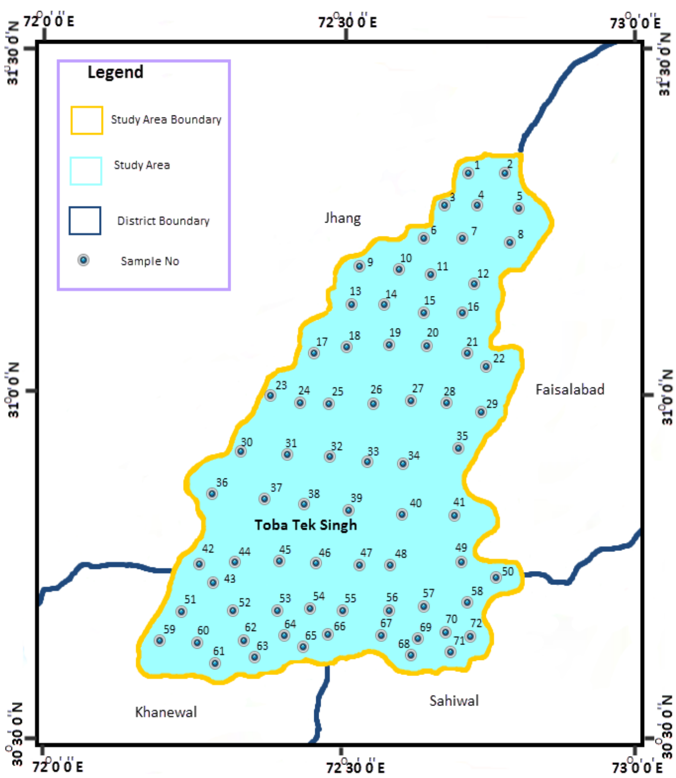

Figure 1: Location of samples in investigated area.

on its rivers and the canal system. Chenab and Ravi supply most of the water through inter river link canals. Ravi River also provides some water during flood season. The ground surface generally slopes in southwest direction. The groundwater is the main source of drinking and irrigation water with the supplement of canal water in the study area. The recharge of groundwater in the area is mostly through the river and canal system. Rainfall also plays a role to recharge the groundwater during monsoon. Through infiltration, the precipitation reaches the water reservoir under the ground. The rainfall in the area is not enough to recharge the ground water for drinking and irrigation purpose, so the rivers are the main source to recharge the groundwater resources. The analysis of data shows that groundwater quality in the study area is generally good or marginally acceptable for drinking and irrigation purposes. However, the decline in groundwater quality is visible and can cause long term sustainability issues, if the proper actions are not taken in time.

Materials and Methods

Sample collection and preservation

A sum-total 72 nos. groundwater samples were collected from different bore-wells at average depth of 50 m to 120 m. Locations of these samples are presented in Figure 1. Sampling collection and preservation were carried out according to the standard procedures [44,45], and then the tested data were interpreted on the basis of physiochemical analysis. Samples of physicochemical parameters were taken into 2L pre-cleaned polythene kegs. In order to avoid from contamination, special care was taken during sample collection, processing and transportation. The bottle was rinsed three times with groundwater filtered through 0.45 mm mixed cellulose ester membrane before the sample collection. Before analysis samples were preserved at approximately 4°C.

Sample analysis

Physicochemical parameters like total hardness, $CaCO^{-}_{3}$, Ca^{2+}, Mg^{2+} of collected samples were analyzed as per standard methods [46,47]. The analysis of samples for water quality was carried out for main anions, such as, sulphate, bicarbonate and chloride; the cations such as calcium, sodium, magnesium and potassium; and the physiochemicals such as pH, electrical conductivity and total dissolved solids as per standard procedures. Seventy two water samples were collected and analyzed for 11 physicochemical water quality parameters including sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO^{-}_{3}), chloride (Cl^-), sulphate (SO_4^{2-}), pH, electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) in the laboratory of Pakistan Council of Research in Water Resource (PCRWR), using Standard Methods for the Examination of Water (Table 1).

In order to verify the accuracy, the international standard referential materials and the synthetic solutions were applied to the samples. The mean values were used for calculations. The recovery was greater than 95% for the standard referential materials. The methods applied for the determination of the other variables, not practiced in the referential materials, were checked by using synthetic aqueous solutions. The data were also checked at two different independent laboratories, and a maximum of ± 5% deviation was observed.

Results and Discussion

Statistical analysis

The classical use of groundwater hydrology is to produce information about water quality. It not only provides information about the environment where the water has circulated, but also helps understanding the suitability of drinking and irrigation water. Drinking and irrigation water quality was assessed on the basis of analytical results. World Health Organization [48], Pakistan Standards and Quality Control Authority [49], and Pakistan Council of Research in Water Resources [50] limits were considered as standard for drinking water quality. The irrigation water quality was assessed on the basis of the guideline provided by the Food and Agriculture Organization (FAO) of the United Nations [39]. Suitability of groundwater for drinking and irrigation was also assessed on the basis of several other classifications. The results of physicochemical analysis for drinking and irrigation water quality collected from different locations in Toba Tek Singh District are given in Tables 2 and 3, respectively. The analytical results of physicochemical parameters for drinking and irrigation water quality were transformed into descriptive statistical parameters, such as minimum, maximum, mean, median and standard deviation for the entire study period (Table 4).

S. No	Parameters	Analytical Method
1	Bicarbonate	2320, Standard method (1992)
2	Calcium (mg/L)	3500-Ca-D, Standard Method (1992)
3	Chloride (mg/L)	Titration (Silver Nitrate), Standard Method (1992)
4	Conductivity (mS/cm)	E.C meter, Hach-44600-00, USA
5	Hardness (mg/L)	EDTA Titration, Standard Method (1992)
6	Magnesium (mg/L)	2340-C, Standard Method (1992)
7	pH at 25°C	pH Meter, Hanna Instrument Model 8519, Italy
8	Potassium (mg/L)	Flame photometer PFP7, UK
9	Sodium (mg/L)	Flame photometer PFP7, UK
10	Sulfate (mg/L)	SulfaVer4 (Hach-8051) by Spectrophotometer
11	TDS (mg/L)	2540C, Standard method (1992)

Table 1: Methods used for water samples preservation and analysis.

Drinking water quality

Water quality is the physical, chemical and biological characteristics of water [51]. The water quality varies and depends on the variations in geological formations. Different elements present in the groundwater depend on the associated rock bodies and the time it has been in contact with geological material. Groundwater is the only safe and reliable source of drinking water in Toba Tek Singh District. The parameters such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO^{-}_{3}), chloride (Cl^-), sulphate (SO_4^{2-}), pH, electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) are regarded as critical determinants for most development studies of water quality [52]. On the basis of the comparison of groundwater quality data with World Health-Organization [48], Pakistan Standards and Quality Control Authority [49] and Pakistan Council of Research in Water Resources [50], the suitability of drinking water was determined. The number and percentage of the samples which exceeded the permissible limits are given in Table 5. It was observed from Table 5 that majority of the samples were in the safe range, except some of the samples such as pH, electrical conductivity (EC), total dissolved solids (TDS), sulphate (SO_4^{2-}), chloride (Cl^-), magnesium (Mg^{2+}) and calcium (Ca^{2+}). Generally, the groundwater quality in most of the study area is suitable for drinking purposes.

pH: pH is regarded as one of the most commonly used parameters to test soil and water. It indicates the acidic or alkaline potential of water and is calculated on a scale of 1-14. The pH value of 7 represents neutral water; less than 7 indicates acidic and greater than 7 shows basic water. Generally, water with pH range of 6.5~8.5 recommended by WHO and

S. No	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L	TDS mg/L	E.C µS/cm	TH mg/L	pH
1	56	35	82	8.6	195	56	180	525	955	285	7.9
2	32	17	16	2.9	115	14	43	201	366	150	7.2
3	40	24	17	4.2	135	15	77	262	477	200	7.8
4	84	22	78	8.5	175	49	187	528	960	300	7.5
5	46	18	14	3.8	145	13	53	228	415	190	7.6
6	48	17	21	5.9	140	27	47	257	468	190	7.6
7	32	11	17	2.5	85	24	41	194	352	125	8.3
8	42	29	41	4	145	35	98	331	602	210	8.2
9	76	53	121	8.9	280	57	286	795	1325	410	7.7
10	60	36	95	11.6	270	45	202	635	1059	300	7.9
11	72	49	111	10.7	275	69	277	756	1260	380	7.3
12	40	10	7	2.3	110	10	27	166	301	140	7.5
13	30	9	6	2	100	4	28	138	250	110	7.3
14	76	46	32	3.3	95	6	23	138	250	380	7.1
15	74	29	31	8	220	25	106	429	780	305	7.5
16	34	26	28	13	200	4	68	289	526	190	8.1
17	36	9	25	3.4	95	34	37	209	380	125	7.4
18	34	9	7	2.8	100	5	27	152	277	120	7.4
19	42	18	82	4.4	230	24	94	418	760	180	7.7
20	34	9	142	5.2	245	34	43	479	870	120	7.9
21	42	18	7	2.5	100	7	19	141	260	180	6.8
22	34	9	6	5	80	7	22	120	218	120	7.7
23	32	11	5	2.3	110	3	20	140	254	125	7.1
24	24	6	33	4.8	150	56	51	319	580	85	7.2
25	36	6	8	2.7	95	9	20	141	256	115	7.2
26	48	17	6	2.7	95	3	24	134	244	190	7.2
27	32	10	5	2	100	10	22	141	257	120	7.2
28	38	4	10	2.5	120	5	30	172	312	110	6.9
29	24	11	7	2.9	320	190	32	407	740	105	7.4
30	40	10	8	4.1	125	10	29	182	330	140	8.0
31	88	24	62	3	370	14	58	499	908	320	7.6
32	70	45	35	1.7	160	21	85	317	576	360	8.1
33	162	21	10	5.3	335	5	16	396	720	340	7.5
34	60	15	7	2.4	130	12	38	202	367	210	6.9
35	28	7	10	4.2	110	9	43	146	338	110	8.2
36	34	15	12	3.8	110	9	21	147	268	145	7.5
37	32	12	5	2.6	90	9	31	146	265	130	7.5
38	34	16	9	3.5	140	6	26	190	345	150	8.2
39	36	5	8	3	145	10	25	206	375	110	7.8
40	16	17	7	2.8	130	5	30	191	348	110	8.0
41	38	17	9	2.5	100	49	151	424	770	165	8.5
42	40	10	59	5.6	130	13	42	205	373	140	7.8
43	40	24	10	3	100	4	21	143	260	200	8.2
44	28	19	7	3.3	145	36	83	309	562	150	8.2
45	28	10	6	2	180	5	21	226	410	110	8.0
46	20	5	8	3.9	95	2	21	132	236	70	8.2
47	42	26	5	2.1	75	6	23	144	262	210	8.5
48	28	10	6	3.1	300	15	90	453	823	110	7.8
49	26	9	62	4.4	120	9	42	193	350	102	8.2
50	56	78	180	8.4	350	106	418	1248	2080	460	7.7
51	36	12	21	2.8	335	10	142	539	980	140	9.6
52	32	10	7	2.6	70	7	30	136	248	120	9.5
53	42	11	7	3.2	25	3	20	98	174	150	10.0
54	48	26	187	8	275	480	391	1842	3070	225	7.3
55	30	19	5	3	45	1	20	99	155	155	9.2
56	24	5	8	2.1	135	1	32	189	324	80	8.2
57	36	13	6	3.5	75	4	24	123	224	145	8.2
58	20	17	5	2	430	91	121	754	1350	120	7.2
59	38	23	29	4.5	135	4	38	210	381	190	8.2

60	60	12	198	7.8	115	61	72	342	622	200	7.1
61	36	10	32	3.7	105	6	27	153	261	130	6.8
62	30	11	5	2.5	100	3	26	151	274	120	6.9
63	50	28	4	3.6	90	1	23	130	236	140	6.9
64	36	2	5	1.9	75	9	29	134	244	100	7.0
65	32	7	6	2.2	90	6	24	136	247	110	6.5
66	38	12	6	3.2	70	5	27	115	202	145	7.1
67	60	17	42	9.8	85	4	25	135	246	220	6.6
68	20	5	4	3	20	4	25	91	165	70	9.4
69	36	2	5	2.1	85	7	28	135	244	100	6.3
70	32	5	47	4.7	100	10	18	132	234	100	7.2
71	40	15	7	3.6	170	45	40	246	447	160	7.5
72	30	9	22	2.3	285	11	123	582	1058	110	7.4

Table 2: Parameters of groundwater quality (mg/L).

S/N	Ca^{2+} meq/L	Mg^{2+} meq/L	Na^{+} meq/L	K^{+} meq/L	HCO_3^- meq/L	Cl^- meq/L	SO_4^{2-} meq/L	PS %	PI %	KR -	SAR -	RSBC meq/L	Mg^{2+}/Ca^{2+} -	MAR %
1	2.8	2.92	3.56	0.22	3.20	1.6	3.75	39.79	57.64	0.62	2.10	0.4	1.04	51.04
2	1.6	1.42	0.69	0.07	1.88	0.4	0.89	20.10	55.56	0.23	0.56	0.28	0.89	47.01
3	2	2	0.74	0.11	2.21	0.43	1.60	17.52	46.97	0.18	0.52	0.21	1	50
4	4.2	1.83	3.39	0.22	2.87	1.4	3.90	37.45	53.97	0.56	1.95	-1.33	0.44	30.34
5	2.3	1.5	0.61	0.10	2.38	0.37	1.10	15.74	48.81	0.16	0.44	0.08	0.65	39.47
6	2.4	1.42	0.91	0.15	2.29	0.77	0.98	21.72	51.23	0.24	0.66	-0.11	0.59	37.17
7	1.6	0.92	0.74	0.06	1.39	0.68	0.85	24.1	58.86	0.29	0.66	-0.21	0.57	36.50
8	2.1	2.42	1.78	0.10	2.38	1	2.04	29.37	52.74	0.39	1.18	0.28	1.15	53.53
9	3.8	4.42	5.26	0.23	4.59	1.63	5.96	40.04	54.91	0.64	2.59	0.79	1.16	53.77
10	3	3	4.13	0.30	4.43	1.28	4.21	42.47	61.55	0.69	2.38	1.43	1	50
11	3.6	4.01	4.83	0.27	4.51	1.97	5.77	40.12	55.90	0.63	2.48	0.91	1.11	52.69
12	2	0.83	0.30	0.06	1.80	0.28	0.56	11.28	52.45	0.11	0.25	-0.2	0.41	29.32
13	1.5	0.75	0.26	0.05	1.64	0.11	0.58	12.11	61.38	0.11	0.24	0.14	0.5	33.33
14	3.8	3.83	1.39	0.08	1.56	0.17	0.48	16.15	29.26	0.18	0.71	-2.24	1.01	50.19
15	3.7	2.42	1.35	0.20	3.61	0.71	2.21	20.21	43.51	0.22	0.77	-0.09	0.65	39.54
16	1.7	2.17	1.22	0.33	3.28	0.11	1.42	28.61	59.58	0.31	0.88	1.58	1.27	56.03
17	1.8	0.75	1.09	0.09	1.56	0.97	0.77	31.63	64.26	0.43	0.96	-0.24	0.42	29.41
18	1.7	0.75	0.30	0.07	1.64	0.14	0.56	13.12	57.48	0.12	0.27	-0.06	0.44	30.61
19	2.1	1.5	3.56	0.11	3.77	0.68	1.96	50.48	76.84	0.99	2.65	1.67	0.71	41.66
20	1.7	0.75	6.17	0.13	4.02	0.97	0.89	72	94.84	2.52	5.57	2.32	0.44	30.61
21	2.1	1.5	0.30	0.06	1.64	0.2	0.39	9.09	40.53	0.08	0.22	-0.46	0.71	41.66
22	1.7	0.75	0.26	0.13	1.31	0.2	0.46	13.73	51.83	0.11	0.23	-0.39	0.44	30.61
23	1.6	0.92	0.22	0.06	1.80	0.09	0.42	10	56.99	0.09	0.19	0.2	0.57	36.50
24	1.2	0.5	1.43	0.12	2.46	1.6	1.06	47.69	95.80	0.84	1.55	1.26	0.42	29.41
25	1.8	0.5	0.35	0.07	1.56	0.26	0.42	15.44	60.34	0.15	0.33	-0.24	0.28	21.73
26	2.4	1.42	0.26	0.07	1.56	0.08	0.5	7.95	36.98	0.07	0.19	-0.84	0.59	37.17
27	1.6	0.83	0.22	0.05	1.64	0.28	0.46	10	56.63	0.09	0.20	0.04	0.52	34.16
28	1.9	0.33	0.43	0.06	1.97	0.14	0.62	18.01	68.93	0.19	0.41	0.07	0.17	14.79
29	1.2	0.92	0.30	0.07	5.24	5.43	0.67	14.86	106.9	0.14	0.29	4.04	0.77	43.39
30	2	0.83	0.35	0.10	2.05	0.28	0.60	13.72	56.03	0.12	0.29	0.05	0.41	29.32
31	4.4	2	2.69	0.07	6.06	0.4	1.21	30.13	56.67	0.42	1.50	1.66	0.45	31.25
32	3.5	3.75	1.52	0.04	2.62	0.6	1.77	17.71	35.79	0.21	0.80	-0.88	1.07	51.72
33	8.1	1.75	0.43	0.13	5.49	0.14	0.33	5.38	26.97	0.04	0.19	-2.61	0.22	17.76
34	3	1.25	0.30	0.06	2.13	0.34	0.79	7.81	38.67	0.07	0.20	-0.87	0.42	29.41
35	1.4	0.58	0.43	0.11	1.80	0.26	0.89	21.43	73.51	0.22	0.43	0.4	0.41	29.29
36	1.7	1.25	0.52	0.10	1.80	0.26	0.44	17.37	53.65	0.18	0.43	0.1	0.74	42.37
37	1.6	1	0.22	0.07	1.47	0.26	0.64	10.03	50.87	0.08	0.19	-0.125	0.62	38.46
38	1.7	1.33	0.39	0.09	2.29	0.17	0.54	13.67	55.65	0.13	0.32	0.59	0.78	43.89
39	1.8	0.42	0.35	0.08	2.38	0.28	0.52	16.23	73.65	0.16	0.33	0.58	0.23	18.91
40	0.8	1.42	0.30	0.07	2.13	0.14	0.62	14.28	69.82	0.13	0.28	1.33	1.77	63.96
41	1.9	1.42	0.39	0.06	1.64	1.4	3.14	11.94	45.03	0.12	0.30	-0.26	0.75	42.77
42	2	0.83	2.56	0.14	2.13	0.37	0.87	48.82	74.57	0.90	2.15	0.13	0.41	29.32
43	2	2	0.43	0.08	1.64	0.11	0.44	11.31	38.61	0.11	0.30	-0.36	1	50
44	1.4	1.58	0.30	0.08	2.38	1.03	1.73	11.31	56.18	0.10	0.24	0.98	1.13	53.02

45	1.4	0.83	0.26	0.05	2.95	0.14	0.44	12.20	79.42	0.12	0.25	1.55	0.59	37.21
46	1	0.41	0.35	0.1	1.56	0.06	0.44	24.17	90.75	0.25	0.42	0.56	0.41	29.17
47	2.1	2.17	0.22	0.05	1.23	0.17	0.48	5.95	29.60	0.05	0.15	-0.87	1.03	50.81
48	1.4	0.83	0.26	0.08	4.92	0.43	1.87	13.23	99.52	0.12	0.25	3.52	0.59	37.21
49	1.3	0.75	2.69	0.11	1.97	0.26	0.87	57.73	86.36	1.31	2.66	0.67	0.58	36.58
50	2.8	6.5	7.83	0.21	5.74	3.03	8.71	46.37	59.69	0.84	3.63	2.94	2.32	69.89
51	1.8	1	0.91	0.07	5.49	0.28	2.96	25.92	87.68	0.32	0.77	3.69	0.55	35.71
52	1.6	0.83	0.30	0.07	1.15	0.2	0.62	13.21	50.27	0.12	0.27	-0.45	0.52	34.15
53	2.1	0.91	0.30	0.08	0.41	0.08	0.42	11.20	28.39	0.10	0.24	-1.69	0.43	30.27
54	2.4	2.17	8.13	0.20	4.51	13.71	8.14	64.57	80.74	1.78	5.38	2.11	0.90	47.48
55	1.5	1.58	0.22	0.08	0.74	0.03	0.42	8.87	32.73	0.07	0.18	-0.76	1.05	51.29
56	1.2	0.42	0.35	0.05	2.21	0.03	0.67	19.80	93.23	0.22	0.39	1.01	0.35	25.92
57	1.8	1.08	0.26	0.09	1.23	0.11	0.5	10.83	43.60	0.09	0.22	-0.57	0.6	37.5
58	1	1.42	0.22	0.05	7.05	2.6	2.5	10.04	108.9	0.09	0.20	6.05	1.42	58.67
59	1.9	1.92	1.26	0.11	2.21	0.11	0.79	26.40	54.07	0.33	0.91	0.31	1.01	50.26
60	3	1	8.61	0.2	1.88	1.74	1.5	68.77	79.15	2.15	6.09	-1.12	0.33	25
61	1.8	0.83	1.39	0.09	1.72	0.17	0.56	36.01	67.20	0.53	1.21	-0.08	0.46	31.55
62	1.5	0.92	0.22	0.06	1.64	0.08	0.54	10.37	56.84	0.09	0.20	0.14	0.61	38.01
63	2.5	2.33	0.17	0.09	1.47	0.03	0.48	5.11	27.65	0.03	0.11	-1.03	0.93	48.24
64	1.8	0.17	0.22	0.05	1.23	0.26	0.60	12.05	60.69	0.11	0.22	-0.57	0.09	8.62
65	1.6	0.58	0.26	0.06	1.47	0.17	0.5	12.8	60.34	0.12	0.25	-0.13	0.36	26.60
66	1.9	1	0.26	0.08	1.15	0.14	0.56	10.49	42.16	0.09	0.21	-0.75	0.53	34.48
67	3	1.42	1.83	0.25	1.39	0.11	0.52	32	48.14	0.41	1.23	-1.61	0.47	32.12
68	1	0.42	0.17	0.08	0.33	0.11	0.52	14.97	46.82	0.12	0.20	-0.67	0.42	29.57
69	1.8	0.17	0.22	0.05	1.39	0.2	0.58	12.05	63.88	0.11	0.22	-0.41	0.09	8.62
70	1.6	0.42	2.04	0.12	1.64	0.28	0.37	51.67	81.79	1.01	2.03	0.04	0.26	20.79
71	2	1.25	0.30	0.09	2.79	1.28	0.83	10.71	55.50	0.09	0.23	0.79	0.62	38.46
72	1.5	0.75	0.96	0.06	4.67	0.31	2.56	31.19	97.23	0.43	0.90	3.17	0.5	33.33

Table 3: Parameters of ground water quality (meq/L).

Parameters	Units	Minimum	Maximum	Mean	Median	S.D
pH	-	6.3	10	7.7	7.6	0.71
EC	(µS/cm)	155	3070	529.25	351	465.12
TDS	(mg/L)	91	1842	303	193.5	287.49
Ca^{2+}	(mg/L)	16	162	42.36	36	21.04
Mg^{2+}	(mg/L)	2	78	17.14	12.5	13.09
Na^{+}	(mg/L)	4	198	31.15	9.5	44.6
K^{+}	(mg/L)	1.7	13	4.17	3.25	2.5
HCO_3^-	(mg/L)	20	430	151.11	120	87.73
Cl^-	(mg/L)	1	480	27.33	9.5	61.67
Cl^-	(meq/L)	0.03	13.71	0.78	0.27	1.76
SO_4^{2-}	(mg/L)	16	418	66.71	31.5	80.97
TH	(mg/L)	70	460	172.66	142.5	86.13
RSBC	(meq/L)	-2.61	6.05	0.36	0.07	1.44
PS	%	5.11	72	22.79	15.94	16.02
MAR	%	8.62	69.89	37.65	36.87	12.12
SAR	-	0.11	6.09	0.95	0.36	1.27
KR	-	0.03	2.52	0.35	0.16	0.47
PI	%	26.97	108.91	60.15	56.65	19.47
Mg^{2+}/Ca^{2+}	-	0.09	2.32	0.67	0.58	0.38

Table 4: Statistical distribution of physicochemical parameters in the groundwater (n=72).

PSQCA is considered as safe for drinking purpose. PCRWR suggested range of pH is 6.5~9.2. In study area, pH varied from 6.3 to 10, with mean value of 7.7, median of 7.6, and standard deviation of 0.71 (Table 4). It was observed from Table 5 that most of the samples had pH levels within the safe limits of WHO, PSQCA and PCRWR. 8% of samples were not within the permissible limit of WHO and PSQCA, while 6% of samples were out of the safe limit set by PCRWR.

Electrical conductivity (EC): Electrical conductivity measures the water ability to conduct an electric current. It signifies the amount of total dissolved salts and is very useful for assessing the purity of water [53]. It is generally used to estimate the amount of total dissolved solids and minerals. It increases with the reaching of dissolved minerals. In the study area, EC values ranged from 155 to 3070 µS/cm, with mean value of 529.25 µS/cm, median of 351 µS/cm, and standard deviation of 465.12 µS/cm (Table 4). EC standard limit for drinking water is 1500 µS/cm as recommended by WHO and PSQCA. PCRWR safe limit

Parameters	Permissible limits								
	(WHO, 2008)			(PSQCA, 2004)			(PCRWR, 2005)		
	Range	Samples exceeding limit	samples %age	Range	Samples exceeding limit	samples %age	Range	Samples exceeding limit	samples %age
pH	6.5- 8.5	6	8	6.5- 8.5	6	8	6.5-9.2	4	6
EC (µS/cm)	1500	2	3	1500	6	3	2343	1	1
TDS (mg/L)	1000	2	3	1000	2	3	1500	1	1
Ca^{2+} (mg/L)	100	1	1	200	-	-	200	-	-
Mg^{2+} (mg/L)	50	2	3	100	-	-	150	-	-
Cl^{-} (mg/L)	250	1	1	500	-	-	600	-	-
SO_4^{2-} (mg/L)	200	5	7	400	1	1	400	1	1
Na^{+} (mg/L)	200	-	-	200	-	-	200	-	-
K^{+} (mg/L)	55	-	-	50	-	-	50	-	-
HCO_3^{-} (mg/L)	600	-	-	500	-	-	500	-	-
TH (mg/L)	500	-	-	500	-	-	500	-	-

Table 5: The comparison of groundwater parameters with international standards for drinking.

of EC for drinking water is 2343 µS/cm. Table 5 showed that 3% of samples were out of safe limit of WHO and PSQCA. Only 1% samples were not within standard limit of PCRWR. Overall 97% of the samples were safe for drinking water.

Total dissolved solids (TDS): The Total dissolved solids generally indicate the amount of minerals and solids dissolved in water. High values of TDS change the taste, corrosive property and hardness of the water [54-56]. High concentrations of TDS are due to the presence of sulphates, chlorides, bicarbonates, carbonates and calcium [57,58]. The measurement of specific conductivity is the most commonly used method for determining TDS [59]. EC values can be converted to TDS values by multiplying EC by a factor varying with the type of water. This factor ranges from 0.5 to 0.9 [60]. The maximum contaminant limit of TDS for drinking water is 1000 mg/L as given by WHO and PSQCA, and 1500 mg/L by PCRWR standard. In the study area, TDS values varied from 91 to 1841 mg/L with mean, median and standard deviation of 303 mg/L, 193.5 mg/L and 287.49 mg/L, respectively (Table 4). According to Table 5, 3% of the water samples were classified as unacceptable using WHO and PSQCA standard, only 1% samples were not within safe limit of PCRWR. Most of the samples were found within safe limit for drinking water.

The palatability of drinking water studied by panels of taters based on its TDS level was given in Table 6 [52,59]. According to Table 6, 68% of samples belonged to excellent water class and 24% samples were found in good water class as categorized by WHO [59]. According to the water class given by Kumar et al. [52], 97% samples were placed in fresh water category, while only 3% in brackish water class. Hence, based on different classifications of TDS, the water in the study area is good for drinking purpose.

Total hardness (TH): Total hardness depends on calcium and magnesium ions [61]. It was calculated by Ragunath [62] using the formula:

$$TH=(Ca^{2+}+Mg^{2+}) \times 50 \quad (1)$$

TH values in the study area varied from 70 to 460 mg/L with mean values of 172.66 mg/L, median of 142.5 mg/L and standard deviation of 86.13 mg/L (Table 4). The permissible limit of TH recommended by WHO, PSQCA and PCRWR is 500 mg/L as given in Table 5. None of the samples in the study area exceeded this limit. The groundwater for drinking was also classified into four different categories like soft, moderately hard, hard and very hard based on TH in Table 6 [63]. Table 6 shows that 57% of samples belonged to moderately hard category, while 29% samples were regarded as hard, and only 11% samples fell in very hard water category. The results show that the water quality based on TH is over all permissible for drinking purpose in the study area.

TDS (mg/L)	Water class	Number of samples	samples %age
<300	Excellent	49	68
300-600	Good	17	24
600-900	Fair	4	5
900-1200	Poor	-	-
>1200	unacceptable	2	3
0-1000	Fresh	70	97
1001-10000	Brackish	2	3
10001-100000	Salty	-	-
>100000	Brine	-	-

Table 6: Suitability of groundwater for drinking based on the values of TDS.

Chloride (Cl^{-}): Chloride is the major ion associated with Individual Septic Disposal (ISDSS) [64]. It is found in all natural waters with relatively small amounts. It can also be derived from human sources. Chloride can affect the food taste [47]. However, it does not cause any health hazard. In the study area, the range of chloride values was from 1 to 480 mg/L with mean, median and standard deviation of 27.33 mg/L, 9.5 mg/L and 61.67 mg/L, respectively (Table 4). The permissible limit of chloride for drinking water is 250 mg/L set by WHO, 500 mg/L by PSQCA, and 600 mg/L by PCRWR. It was observed in Table 5 that only 1% of the samples exceeded the permissible limit of WHO, while no sample exceeded the safe limit of PSQCA and PCRWR. Hence, the water quality for drinking purpose is permissible based on chloride in the study area.

Sulphate (SO_4^{2-}): Sulphate occurs in groundwater in the form of inorganic sulphate and dissolved gas (H_2S). It is not a harmful substance, although high values of sulphate in groundwater may have laxative consequence. The concentrations of sulphate in the study area varied from 16 to 418 mg/L with mean of 66.71 mg/L, median of 31.5 mg/L and standard deviation of 80.97 mg/L (Table 4). The safe limits of sulphate given by WHO is 200 mg/L, 400 mg/L recommended by PSQCA and PCRWR. Table 5 showed that 7% samples were not in the safe range of WHO, while only 1% samples exceeded the permissible limit of PSQCA and PCRWR. So, overall water quality is good in the study area on the basis of sulphate concentrations.

Bicarbonate (HCO_3^{-}): The main source of bicarbonate ions in groundwater is the dissolution of carbonate rocks and the carbonate species, and the pH of water is usually from 5 to 7 [65]. It was observed that all dissolved carbonate species convert to H_2CO_3 below pH=6, while the ratio of CO_3 and H_2CO_3 increases above pH=7 [66]. In the study area, the values of bicarbonate ranged from 20 to 430 mg/L with the mean, median and standard deviation of 151.11 mg/L, 120 mg/L and 87.73 mg/L, respectively (Table 4). The permissible limits of bicarbonate for drinking water given by WHO are 600 mg/L; and 500 mg/L set by PSQCA and PCRWR. All the samples were found within the safe limit of WHO, PSQCA and PCRWR. Hence, the drinking water quality is permissible on the basis of bicarbonate values.

Calcium (Ca^{2+}): Calcium is the fifth most common element present in natural waters and it contributes to the water hardness. Calcite, gypsum, aragonite and anhydrite are the main source of calcium in groundwater, especially in sedimentary rocks. Granitic terrain is the natural source of calcium and has large concentration of such elements [67]. In the study area, calcium values varied from 16 to 162 mg/L with mean values of 42.36 mg/L, median values of 36 mg/L and standard deviation of 21.04 mg/L (Table 4). The standard limit of calcium for drinking water set by WHO is 100 mg/L. The permissible limit given by PSQCA and PCRWR is 200 mg/L. Only 1% of samples crossed the limit given by WHO, while all the samples were within the permissible limits set by PSQCA and PCRWR. So, on the basis of calcium concentration, groundwater is safe for drinking purpose in the study area.

Magnesium (Mg^{2+})": Magnesium is regarded as one of the most common elements within the earth's crust. It is found in all natural waters. It contributes to water hardness. Dolomites and mafic minerals in rocks are the main source of magnesium in natural waters. In the study area, magnesium values ranged from 2 to 78 mg/L with mean values of 17.14 mg/L, median values of 12.5 mg/L and standard deviation of 13.09 mg/L (Table 4). The permissible limit of magnesium for drinking purpose is 50 mg/L given by WHO, 100 mg/L by PSQCA and 150 mg/L by PCRWR. Only 3% of the samples were not within the permissible limit of WHO, while all the samples were found within the safe limits of PSQCA and PCRWR. Hence, groundwater is safe for drinking purpose on the basis of magnesium values.

Sodium (Na^+): Sodium is the most important natural mineral. Granitic terrain decomposition increases the concentration of sodium ion [67]. In the study area, sodium values were in the range of 4 to 198 mg/L with mean of 31.15 mg/L, median of 9.5 mg/L and standard deviation of 44.6 mg/L (Table 4). The permissible limit of sodium for drinking purpose is 200 mg/L given by WHO, PSQCA and PCRWR. All the samples were found within the permissible limits of WHO, PSQCA and PCRWR. Hence, groundwater quality is safe for drinking purpose on the basis of sodium values.

Potassium (K^+): Potassium is considered as one of the most important natural minerals. The decomposition of granitic terrain increases potassium ion concentration [67]. In the study area, potassium values varied from 1.7 to 13 mg/L with mean of 4.17 mg/L, median of 3.25 mg/L and standard deviation of 2.5 mg/L (Table 4). The safe limit of potassium for drinking purpose is 55 mg/L set by WHO; and 50 mg/L given by PSQCA and PCRWR. It was observed that all the samples were within the permissible limits of WHO, PSQCA and PCRWR. Hence, groundwater is safe for drinking purpose on the basis of potassium values.

Most of the samples of water quality parameters were found safe for drinking water. Thus, groundwater quality in the study area is suitable for drinking purpose.

Irrigation water quality

The irrigation water quality depends on the constituents of the minerals present in the groundwater [68]. The concentration of dissolved salts, relative proportion of bicarbonate to calcium, magnesium and relative proportion of sodium to calcium are the important chemical constituents, which affect the water quality for irrigation. The major problems of irrigation water quality are salinity and alkalinity. Salts may affect plant growth. The irrigation of food crops has a possible hazard to food consumers if the irrigation water quality is inadequate. The salinity of groundwater for irrigation also depends on the kinds of crops, composition and permeability of soil, the climate of region, the amount of water used the topography of land, the nature of groundwater, as well as the surface water drainage system. In this study, the discussion of irrigation water quality is mainly based on the concentrations of physicochemical parameters (sodium, potassium, calcium, magnesium, bicarbonate, chloride, sulphate, pH, electrical conductivity, total dissolved solids), and other important irrigation water quality parameters, namely sodium adsorption ratio (SAR), percent sodium (PS), permeability index (PI), residual sodium bicarbonate (RSBC), Kelly's ratio (KR), magnesium adsorption ratio (MAR) and residual Mg^{2+}/Ca^{2+} ratio. The calculation of all these parameters was carried out by ionic concentration (meq/L) [30,69-71].

The concentrations of parameters (sodium, potassium, calcium, magnesium, bicarbonate, chloride, sulphate,) for the assessment of irrigation water quality were converted from mg/L to meq/L using the relation:

Unit of parameter in mg/L/equivalent weight of parameter=Unit of parameter in meq/L (2)

The equivalent weights of these parameters are given in Table 7. The irrigation water quality parameters were calculated in meq/L. The results of different irrigation water parameters are given in Table 3, summarized in Table 4.

Physiochemical parameters: The irrigation water quality was assessed on the basis of water quality parameters such as sodium, potassium, calcium, magnesium, bicarbonate, chloride, sulphate, pH, electrical conductivity and total dissolved solids [39]. It was observed in Table 8 that all parameters, except of some samples of pH, EC and Mg^{2+}, were found within permissible limit. 8% samples of pH exceeded the safe limit, while only 3% samples of EC and Mg^{2+} were found unsafe for irrigation water. Hence, the groundwater quality is overall good for irrigation purpose in the study area based on physicochemical parameters.

Salinity: The salinity affects the crop water availability. It is measured on the basis of EC and TDS [39]. Based on the interpretation of EC and TDS for salinity in Table 9, it was found that 75% of EC samples were safe, while 24% of EC samples had slight to moderate effect of salinity, and only 1% samples had severe salinity effect, whereas 82% of TDS samples had no salinity effect, while 18% TDS samples had slight to moderate salinity effect. So, most of the samples show no salinity effect.

Parameters	Equivalent weight
Sodium	23
Potassium	39
Calcium	20
Magnesium	12
Chloride	35
Bicarbonate	61
Sulphate	48

Table 7: Parameters with their equivalent weights.

Specific ion toxicity: It affects the sensitive crops. It is estimated on the basis of sodium (Na^+) and chloride (Cl^-) [39]. The classification of sodium and chloride for specific ion toxicity as given in Table 9, showed that 86% of sodium samples were safe for surface and sprinkler irrigation, while 14% samples had slight to moderate effect of specific ion toxicity, but none had severe effect. For surface irrigation, 98% samples of chloride had no effect of specific ion toxicity, only 1% samples had slight to moderate effect, while 1% samples had severe effect of specific ion toxicity. For sprinkler irrigation based on chloride, 96% samples were safe while 4% samples of chloride hade slight to moderate effect of specific ion toxicity. Hence, overall samples show safe irrigation water quality on the basis of specific ion toxicity.

Miscellaneous effect: It affects susceptible. It is measured on the basis of bicarbonate (HCO_3^-), and pH [39]. It was found that 21% samples of bicarbonate were safe, while 79% had slight to moderate miscellaneous. 89% samples of pH had no miscellaneous effect (Table 9). No severe miscellaneous effect was observed based on bicarbonate and pH. Hence, irrigation water quality is acceptable in the study area based on miscellaneous effects.

Sodium adsorption ratio (SAR): The sodium adsorption ratio was measured by the following equation [70]:

$$SAR = Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+}) / 2]} \quad (3)$$

All ion concentrations were expressed in meq/L. It provides an idea about the adsorption of sodium by soil. It shows the proportion of sodium to calcium and magnesium, which can affect the water availability of crop. The excess of sodium in water reduces the soil permeability [72]. The calculated values of SAR are given in Table 3. SAR varied from 0.11 to 6.09 with mean and median values of 0.95 and 0.36, respectively, the standard deviation is 1.27 (Table 4). According to the classification of SAR [70] in the study area, Table 10 showed that all the samples of SAR had excellent water class and it is acceptable for irrigation in the study area.

Percent sodium (PS): The percent sodium was calculated by the equation given as:

$$PS=[(Na^++K^+)/(Ca^{2+}+Mg^{2+}+Na^++K^+)] \times 100 \quad (4)$$

All the ions were expressed in the unit of meq/L. It is very important to study sodium hazard. High percentage of sodium in the groundwater may affect the plant growth and reduce soil permeability [73]. PS was calculated using above equation and its values are given in Table 3. It ranged from 5.11 to 72 with mean, median and standard deviation values of 22.79, 15.94 and 16.02, respectively (Table 4). The classification of PS [74] is given in Table 10. It was observed in Table 10 that 60% samples were in excellent category, 24% samples in good, 12% samples in permissible, and only 4% in doubtful category. Overall

Water Parameters	Usual Range in Irrigation Water	No. of samples exceeding the permissible limit	%age of samples exceeding the permissible limit
pH	6- 8.5	5	8
EC (μS/cm)	0-3000	1	3
TDS (meq/L)	0-2000	-	-
Ca^{2+} (meq/L)	0-20	-	-
Mg^{2+} (meq/L)	0-5	1	3
Cl^- (meq/L)	0-30	-	-
SO_4^{2-} (meq/L)	0-20	-	-
Na^+ (meq/L)	0-40	-	-
K^+ (meq/L)	0-5	-	-
HCO_3^- (meq/L)	0-10	-	-

Table 8: Water parameters for irrigation water quality.

Potential Irrigation Problem			Range of Values	Degree of Restriction on Use	Number of Samples	%age of Samples
Salinity (affects Crop Water Availability	EC (μS/cm)		<700	None	54	75
			700-3000	Slight to moderate	17	24
			>3000	Severe	1	1
	TDS (mg/L)		<450	None	59	82
			450-2000	Slight to moderate	13	18
			>2000	Severe	-	-
Specific Ion Toxicity (affects sensitive crops)	Na^+ (meq/L)	Surface irrigation	<3	None	62	86
			3-9	Slight to moderate	10	14
			>9	Severe	-	-
		Sprinkler irrigation	<3	None	62	86
			>3	Slight to moderate	10	14
	Cl^- (meq/L)	Surface irrigation	<4	None	70	98
			4-10	Slight to moderate	1	1
			>10	Severe	1	1
		Sprinkler irrigation	<3	None	69	96
			>3	Slight to moderate	3	4
Miscellaneous Effects (affects susceptible	HCO_3^- (meq/L)		<1.5	None	15	21
			1.5-8.5	Slight to moderate	57	79
			>8.5	Severe	-	-
	pH		6.5-8.4	None	64	89

Table 9: Guidelines for interpretations of water quality for irrigation.

Parameters	Range	Water Class	Number of Samples	%age of Samples
PS (%)	0-20	Excellent	43	60
	20-40	Good	17	24
	40-60	Permissible	9	12
	60-80	Doubtful	3	4
	>80	Unsuitable	-	-
PI (%)	>75	Safe	15	21
	25-75	Moderate	57	79
	<25	Unsafe	-	-
Residual Mg^{2+}/Ca^{2+} Ratio	<1.5	Safe	70	97
	1.5-3	Moderate	2	3
	>3	Unsafe	-	-
RSBC (meq/L)	<1.25	Good	57	79
	1.25-2.5	Medium	9	13
	>2.5	Bad	6	8
EC (µS/cm)	<250	Excellent	15	21
	250-750	Good	41	57
	750-2250	Permissible	15	21
	2250-4000	Doubtful	1	1
	>4000	Unsuitable	-	-
SAR	<10	Excellent	72	100
	10-18	Good	-	-
	18-26	Fair	-	-
	>26	Poor	-	-
KR	<1	Suitable	67	93
	>1	Unsuitable	5	7
MAR (%)	<50	Fit	58	81
	>50	Unfit	14	19
TDS (mg/L)	<1000	Non saline	69	96
	1000-3000	Slightly saline	3	4
	3000-10000	Moderately saline	-	-
	>10000	Very saline	-	-
Chloride (C^{l-}) (meq/L)	<0.14	Extremely fresh	15	21
	0.14-0.85	Very fresh	41	57
	0.85-4.23	Fresh	14	20
	4.23-8.46	Fresh brackish	1	1
	8.46-28.21	Brackish	1	1
	28.21-282.06	Brackish salt	-	-
	282.06-564.13	Salt	-	-
	>564.13	Hyper saline	-	-

Table 10: Suitability of groundwater for irrigation based on several classifications.

irrigation water quality is suitable on the basis of percent sodium in the study area.

Residual sodium bi-carbonate (RSBC): The residual sodium bicarbonate was calculated using the formula [75]:

$$RSBC= HCO^{3-}-Ca^{2+} \quad (5)$$

RSBC and concentrations of the constituents were measured in meq/L .The concentration of bicarbonate and carbonate affects the groundwater quality for irrigation. High pH of groundwater increases the concentration of bicarbonate. Therefore, such water makes the irrigated land infertile owing to deposition of sodium carbonate [76]. RSBC values given in Table 3 were calculated using above equation. In the study area, RSBC values varied from -2.61 to 6.05 meq/L with mean, median and standard deviation values of 0.36 meq/L, 0.07 meq/L and 1.44 meq/L respectively (Table 4). The classification of RSBC [70] is given in Table 10. 79% of samples fell in good category, 13% samples in medium and only 8% samples in bad category. Hence, overall water samples are considered safe for irrigation water in the study area.

Magnesium adsorption ratio (MAR): The magnesium adsorption ratio was determined using the given relation [62]:

$$MAR=[Mg^{2+}/(Ca^{2+}+Mg^{2+})] \times 100 \quad (6)$$

All the ionic constituents expressed were in meq/L. The concentration of magnesium in groundwater is one of the most important qualitative criteria to determine the irrigation water quality. Generally, the concentrations of calcium and magnesium maintain the equilibrium state in most of the waters. The soil salinity increases with the increase in magnesium concentration in groundwater [73]. MAR values were calculated using above equation (Table 3). In the study area, MAR values ranged from 8.62 to 69.89 with mean, median and standard deviation of 37.65, 36.87 and 12.12 respectively (Table 4). MAR values in the study area are classified in Table 10 [39]. 81% samples were found in fit category while only 19% samples fell in unfit category. Hence, most of water samples are safe for irrigation water in the study area.

Kelly's ratio (KR): Kelly's ratio is calculated using the following formula:

$$KR=Na^+/(Ca^{2+} + Mg^{2+}) \quad (7)$$

All ionic constituents were presented in meq/L. Kelly's ration with values greater than 1 shows excess concentration of sodium; groundwater is suitable for irrigation with Kelly's ratio less than 1 [71]. KR was calculated using above equation and values are given in Table 3. In the study area, KR varied from 0.03 to 2.52 with mean, median and standard deviation of 0.35, 0.16 and 0.47, respectively (Table 4). The classification of KR in the study area is given in Table 10 [71]. It was observed in Table 10 that 93% samples were found suitable while only 7% samples were studied unsuitable for irrigation. Hence, overall groundwater quality is suitable for irrigation purpose.

Permeability index (PI): The permeability index was calculated using the following formula [70].

$$PI = [\{Na^+ + \sqrt{(HCO^{3-})}\} / Ca^{2+} + Mg^{2+} + Na^+)] \times 100 \quad (8)$$

All ions were expressed in meq/L. It is an important parameter to measure the groundwater suitability for irrigation. It is affected by the long term use of agricultural water; total dissolved solids, sodium bicarbonate and soil type are the influencing constituents. PI calculated values are given in Table 3. In the study area, PI varied from 26.97 to 108.91 with mean, median and standard deviation of 60.15, 56.65 and 19.47, respectively (Table 4). The classification of PI is given in Table 10 [70]. About 21% samples were found complete safe while 79% samples were moderately safe and no sample was found unsafe. Hence, overall groundwater quality is safe for irrigation purpose.

Residual Mg^{2+}/Ca^{2+} ratio": The residual ratio was calculated using the following relation [52]:

$$\text{Residual Ratio}=Mg^{2+}/Ca^{2+} \quad (9)$$

All ions were expressed in meq/L. It is very useful to find the suitability of groundwater for irrigation; groundwater can be classified as suitable or unsuitable on the basis of this residual ratio [52]. This ratio was calculated and values are given in Table 3. In the study area, it ranged from 0.09 to 2.32 with mean, median and standard deviation of 0.67, 0.58 and 0.38, respectively (Table 4). According to the classification of residual ratio as given in Table 10 [70], it was observed that 97% of samples fell in safe category, only 3% samples were found moderately safe and no sample was found unsafe. Hence, groundwater quality is suitable for irrigation purpose.

Total dissolved solids: The total dissolved solids were calculated using the relation (Richards, 1954):

$$\text{TDS (mg/L or ppm)=EC (mmhos/cm or dS/m)} \times 640$$

$$\text{ECW (mmhos/cm or dS/m)} \times 640\text{=TDS (mg/L or ppm)} \quad (10)$$

EC and TDS were expressed in μ-mhos/cm and mg/L, respectively. The salts of calcium, magnesium, potassium, sodium in the irrigation groundwater is harmful to crops; and their excess quantities may affect the osmotic activities of the crops and may prevent adequate aeration. To assess the suitability of water for any purpose, TDS should be less than 500 mg/L [76-78]. The ratio of TDS to EC ranges from 550 to 700 ppm for different salt solutions. The most common salt in saline water is sodium chloride which has TDS of 640 ppm at EC of 1dS/m. Mostly, TDS is calculated from EC using this relation or multiplying by other factors. TDS values are given in Table 2. In the study area, it ranged from 91 to 1842 mg/L with mean, median and standard deviation of 303 mg/L, 193.5 mg/L and 287.49 mg/L, respectively (Table 4). TDS values for irrigation purpose were classified in Table 10 [79]. It was observed that 96% samples had no salinity; only 4% samples were found slightly saline. Hence, groundwater quality based on TDS is safe for irrigation purpose.

Electrical conductivity (EC): EC and TDS have the relation.

EC and TDS were expressed in μ-mhos/cm and mg/L respectively. It is very important parameter to measure the suitability of groundwater for irrigation purpose. The higher the values of EC, the lesser the water available to crops, even the soil is wet because the plants can only transpire the useful water so, the useable water decreases with the increase in EC. It reduces the yield potential of the crops. EC values are given in Table 2. In the study area, it varied from 155 to 3070 (μS/cm) with mean, median and standard deviation of 529.25 μS/cm, 351 μS/cm and 465.12 μS/cm, respectively (Table 4). EC values for irrigation purpose were classified in Table 10 [70]. According to this classification, 21% samples were found excellent, 57% good, 21% permissible and only 1% doubtable. Hence, overall groundwater quality based on EC is good for irrigation purpose.

Chloride (Cl^-): Chloride is one of the important parameters to assess the groundwater quality for any purpose. The groundwater suitability for irrigation purpose can be determined on the basis of chloride concentrations [80]. Chloride values in meq/L are given in Table 3. In the study area, it ranged from 0.03 to 13.71 meq/L with mean, median and standard deviation of 0.78 meq/L, 0.27 meq/L and 1.76 meq/L, respectively (Table 4). Chloride values for irrigation purpose were classified in Table 10 [80]. It was observed that 21% samples fell in extremely fresh category, 57% samples in very fresh category, 20% samples in fresh category, 1% samples in fresh brackish category and 1% samples in brackish category. On the basis of this classification it is concluded that most of the water is fresh and no saline water. Hence, overall groundwater quality based on chloride is safe for irrigation purpose.

Hence, the groundwater quality on the basis of different irrigation water quality parameters is suitable for irrigation in the study area (Table 11).

Correlation analysis

The correlation for physiochemical parameters was done by using bivariate technique. The correlation coefficients are worked out to find out the relationship between physicochemical parameters of the water samples [81]. The close examination of correlation matrix was helpful because it can determine relations between variables that can explain the overall coherence of the data set and point out the contribution of the individual chemical parameters in numerous control factors, a fact which commonly occurred in hydrochemistry. According to this method the change is measured between two variables or more and the value remains between -1 and 1. R measures the correlation between the variables, and is called the correlation coefficient and its value ranges between -1 and 1. The value of R around zero shows no relationship between the variables [82]. Its value around 1 shows very strong correlation. If the value of R is greater than 0.7, then this is taken as strongly correlated for the geochemical study. If it ranges from 0.5 values to 0.7 values then correlation coefficient is moderately correlated. If the value of R is negative value then it means that the

Total Hardness(mg/L)	Types	No of Samples	Samples %age
<75	Soft	2	3
75-150	Moderately hard	41	57
150-300	Hard	21	29
>300	Very hard	8	11

Table 11: The classification of groundwater for drinking based on hardness.

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value of one variable is decreasing with the increase in other variable value [83]. The correlation was carried out for eleven parameters using the linear regressions as represented in Table 12. The ions correlation for the samples of groundwater is as:

Besides very strong correlation (R=0.98) between EC and TDS, strong correlation (R=0.91) also existed between TDS-SO4, EC- SO4 and Mg-TH. pH showed negative correlation with most of the variables. Overall in the study area, EC-TDS, TDS-Na, TDS-HCO_3, TDS-Cl, EC-Na, EC-HCO_3, EC-Cl, EC-SO_4, Ca-TH, Mg-TH, Na-SO_4, had strong correlation more than 0.7. The pairs like TDS-Mg, TDS-K, TDS-TH, EC-Mg, EC-TH, Ca-Mg, Mg-Na, Mg-K, Mg-SO_4, Na-K, Na-Cl, Na-TH, K-SO_4, K-TH, HCO3-HSO4, Cl-SO_4, TH-SO_4 were moderately correlated with correlation coefficient from 0.5 to 0.7. Other pairs had weak correlation with correlation coefficient less than 5.

Graphical analysis

The ions leach out and dissolve in groundwater during the water circulation in soils and rock bodies. The geochemistry of the groundwater is influenced by the factors like geological formations, water-rock interaction and relative mobility of ions [84]. The results of groundwater quality parameters in form of tables may be difficult to interpret. The graphical analysis of groundwater parameters is easy to interpret. In order to assess the groundwater suitability, the graphical interpretation of groundwater parameters was worked out by developing Piper, Durov, Schoeller and Stiff diagrams.

Piper diagram: The concentrations of major anions and cations can be plotted in Piper tri linear diagram to understand the geochemical evolution of groundwater [85]. Rock Ware Aq.QA software was used to plot the Piper diagram. Piper diagrams are the combination of anion and cation triangles which lie on the common baseline; diamond shape between them is used to characterize different types of water. Piper divided the water into four types by placing it near four corners of the diamond. Water plotted at the top of the diamond is considered as high with Ca^{+2}+Mg^{+2} and Cl^-+SO_4^{-2}, which is the area of permanent hardness. The water plot near right side corner is rich in Ca^{+2}+Mg^{+2}; this water region is temporary hardness. The water plot at the lower corner is composed of alkali carbonates (Na^++K^+ and HCO_3^-+CO_3^{-2}). The water near left hand side may be saline water (Na^++k^+ and Cl^-+SO_4^{2-}).

The groundwater samples were plotted in Piper diagram using Rock Ware Aq.QA software in Figure 2. It was observed in piper diagram that the nature of groundwater present in investigated area is sodium sulphate form. Thus, Piper diagram not only identifies the nature of water samples but also uncovers their relationships among each other. The geologic units along with chemically similar water can be predicted and classified followed by trend of water chemistry analysis along with flow path [86].

Durov diagram: Durov diagram can help to identify the types of water for the assessment of quality of groundwater [87]. This diagram

	pH	TDS	EC	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{-2}	TH
pH	1										
TDS	-0.02	1									
EC	-0.03	0.98	1								
Ca^2	-0.16	0.28	0.28	1							
Mg^{2+}	0.03	0.56	0.54	0.5	1						
Na^+	-0.08	0.73	0.72	0.32	0.52	1					
K^+	-0.05	0.53	0.48	0.4	0.52	0.65	1				
HCO_3^-	-0.06	0.73	0.75	0.36	0.42	0.43	0.33	1			
Cl^-	-0.1	0.79	0.81	0.06	0.24	0.56	0.3	0.41	1		
SO_4^{-2}	0.02	0.92	0.91	0.27	0.7	0.74	0.58	0.59	0.65	1	
TH	-0.06	0.52	0.51	0.78	0.91	0.54	0.56	0.44	0.2	0.62	1

Table 12: Correlation between physiochemical parameters.

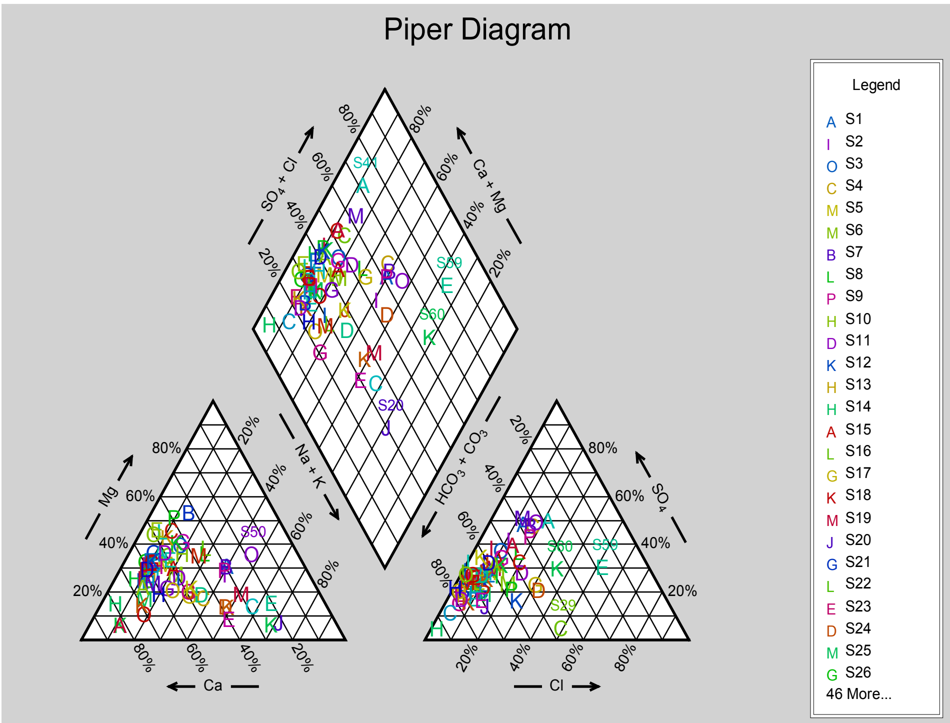

Figure 2: Piper Plot for groundwater parameters in the study area.

is an alternative form of the Piper tri-linear diagram. In Durov diagram, the major cations and anions with percentage of meq/L are set equal to 100% in two base triangles; and the expanded version includes electrical conductivity (μS/cm) and pH data added to the sides of the plot for further comparisons. The data points of the two base triangles are projected in square form which is perpendicular to each triangle. It represents the clustering of data points and the possible geochemical processes which can affect the water quality. This diagram was plotted by using Rock Ware Aq.QA software (Figure 3). The Durov Plot specifies that most of the samples in the study area indicate no dominant anion or cation showing water exhibiting simple dissolution or mixing. Water type of many samples is dominated by Ca^{+2} and HCO_3 ions which show ion exchange process and Na^+ ions indicate probable mixing influences. EC and pH part of the plot shows that overall water quality is suitable for drinking and irrigation purpose in the study area.

Schoeller diagram: The Schoeller diagram is useful for the study of comparative changes in the concentrations and ratios of water quality parameters for different samples [88]. The different water quality parameters were plotted with their concentrations in meq/L as shown in Figure 4. This diagram was generated using Rock Ware Aq.QA software. The results of this diagram show that lines of similar slope with concentrations of different parameters indicate the same source of water. It was observed in this diagram that the most water type of high sodium concentration also has high content of chloride.

Stiff diagram: The geochemistry of groundwater can be studied by means of its major ions [89]. Stiff diagram shows graphical representation of different ions in the groundwater. The average ionic composition analysis of stiff diagram is shown in Figure 5. Stiff diagram was plotted using Rock Ware Aq.QA software [90]. It shows dominance of Na-Cl, while Ca-HCO_3 and Mg-SO_4 are almost equal in their proportion.

Conclusion

The groundwater quality of Toba Tek Singh District was assessed for its drinking and irrigation suitability. This work has presented the levels of physicochemical parameters like pH, electrical Conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}) magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), bicarbonate (HCO^{-3}) and sulphate (SO_4^{2-}) in the well water samples collected from Toba Tek Singh District. The results obtained from the analysis of physicochemical parameters for drinking purpose show that most of the parameters did not exceed the permissible limit set by the world Health Organization (WHO), Pakistan Standards and Quality Control Authority (PSQCA) and Pakistan Council of Research in Water Resources (PCRWR). The analysis of irrigation water parameters such as sodium adsorption ratio (SAR), percent sodium (PS), permeability index (PI), residual sodium bicarbonate (RSBC), Kelly's ratio (KR), and magnesium adsorption ratio (MAR), show that overall groundwater quality in the study area is good for irrigation. Results obtained from graphical analysis (Piper and Durov diagrams) of groundwater samples show that the groundwater is Na-SO_4 type and most of the groundwater samples are in the phase of mixing, dissolution with few in reverse ion exchange. However, the present status of some of the water samples does not meet the international standard of water quality with respect to some constituents, a condition that is possibly to be worst in future. Thus the results obtained from the present investigation shall be helpful for future management of the reservoir water. The physicochemical characteristics of reservoir water suggested that the water in most of Toba Tek Singh District was no harmful to irrigation and drinking water.

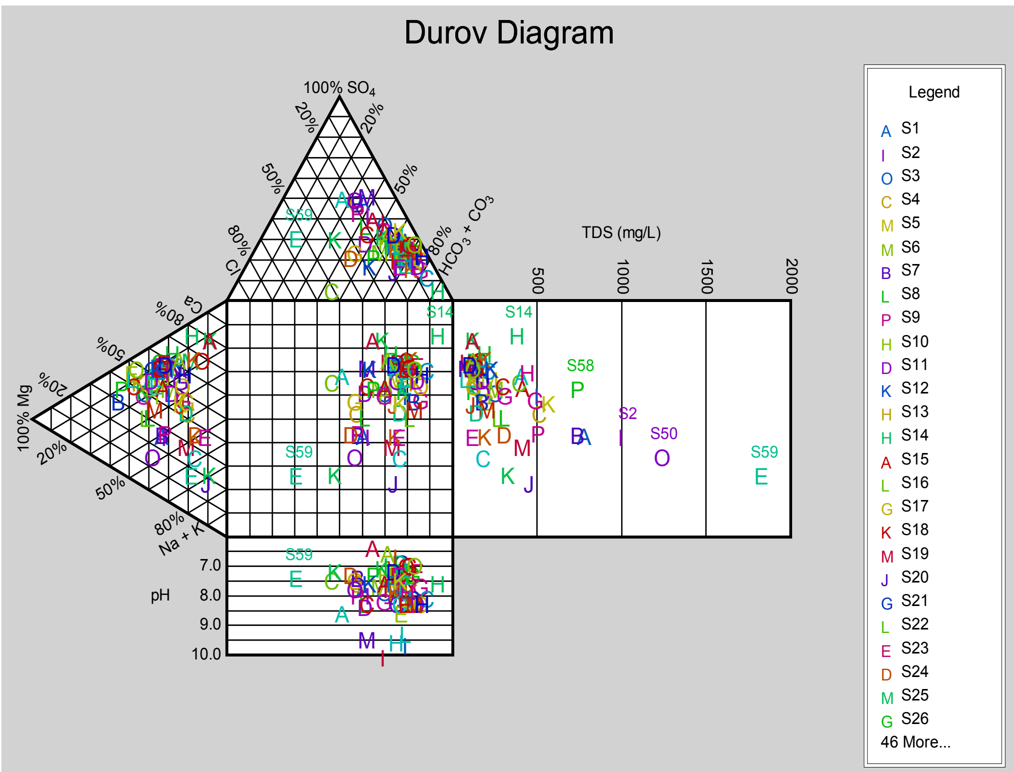

Figure 3: Durov Plot for groundwater parameters in the study area.

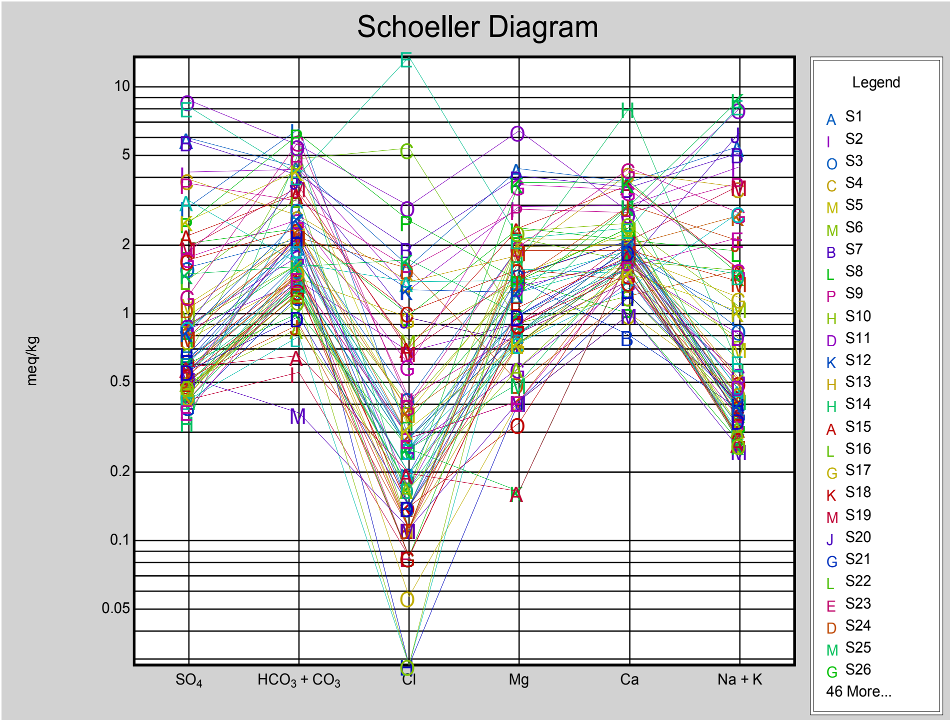

Figure 4: Schoeller Plot for groundwater parameters in the study area.

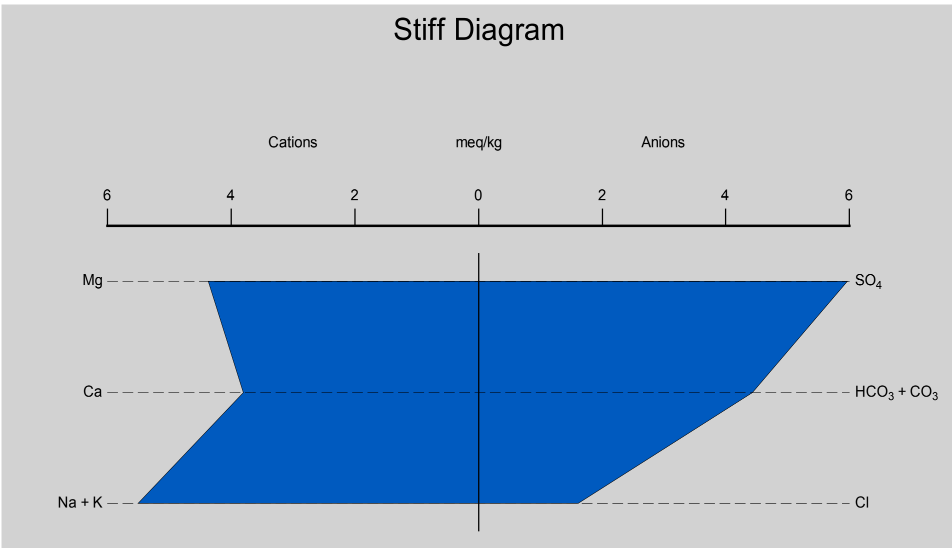

Figure 5: Stiff Plot for groundwater parameters in the study area.

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References

1. McMurry J, Fay RC (2004) Hydrogen, Oxygen and Water, (4th edn.). In: Hamann KP editor. Mc Murry Fay Chemistry. Pearson Education, pp: 575-599.
2. Delleur JD (1999) The Handbook of Groundwater Engineering. CRC Press, USA.
3. Qiu J (2010) China faces up to groundwater crises. Nature 466: 308.
4. Peiyue L, Quan W, Jianhua W (2011) Groundwater suitability for drinking and agricultural usage in Yinchuan Area, China. International Journal of Environmental Sciences 1: 1241-1249.
5. Tadesse N, Bheemalingeswara K, Berhane A (2009) Groundwater suitability for irrigation: a case study from Debre Kidane Watershed, eastern Tigray, Ethopia. MEJS 1: 36-58.
6. Mendie U (2005) The Nature of Water. In: The Theory and Practice of Clean Water Production for Domestic and Industrial Use. Lacto-Medals Publishers, Lagos, pp: 1-21.

7. Chitmanat C, Traichaiyaporn S (2010) Spatial and temporal variations of physical-chemical water quality and some heavy metals in water, sediments and fish of the Mae Kuang River, Northern Thailand. International Journal of Agriculture and Biology 12: 816-820.

8. Mirecki JE, Parks W S (1994) Leachate geochemistry at a municipal landfill, Memphis, Tennessee. Ground Water 32: 390.

9. Manzoor S, Shah MH, Shaheen N, Khalique A, Jaffar M (2006) Multivariate analysis of trace metals in textile effluents in relation to soil and groundwater. Journal of Hazardous Materials 137: 31-37.

10. Manning JC (1997) Applied principles of hydrology. Upper Saddle River, NJ: Prentice Hall.

11. Versari A, Parpinello GP, Galassi S (2002) Chemometric survey of Italian bottled mineral waters by means of their labelled physico-chemical and chemical composition. Journal of Food Compos Anal 15: 251-264.

12. Ackah M, Agyemang O, Anim AK, Osei J, Bentil NO, et al. (2011) Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana. Proc Int Acad Ecol Environmental Sci 1: 186-194.

13. Sayyed MRG, Wagh GS (2011) An assessment of groundwater quality for agricultural use: a case study from solid waste disposal site SE of Pune, India. Proc Int Acad Ecol Environ Sci 1: 195-201.

14. Arms K (2008) Environmental Science. Holt, Rinehart and Witson A Harcourt Education Company.

15. Peterson N, Kennedy M (1997) Water quality trends and geological mass balance. John Whiley and Sons, pp: 139-179.

16. Sayyed MRG, Sayadi MH (2011) Variations in the heavy metal accumulations within the surface soils from the Chitgar industrial area of Tehran. Proc Int Acad Ecol Environ Sci 1: 36-46.

17. WHO (2004) Guidelines for Drinking-Water Quality: Training Pack. WHO, Switzerland.

18. Packham RF (1996) Drinking water quality and health. Pollution, causes, effects and control. The Royal Society of Chemistry, UK, pp: 52-65.

19. Dinrifo RR, Babatunde SOE, Bankole RO, Demu QA (2010) Physicochemical properties of rain water collected from some Industries Areas of Lagos State. Nigeria European Journal of Scientific Research 41: 383-390.

20. Aiyesanmi AF, Ipinmoroti KO, Adeeyinwo CE (2004) Baseline geochemical characteristics of groundwater within Okitipupa south-east belt of the bituminous sands field of Nigeria. International journal of environmental studies 61: 49-57.

21. Helena B, Pardo R, Vega M, Barrado E, Fernandez JM et al., (2000) Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. Water research 34: 807-816.

22. Jobson J (2012) Applied multivariate data analysis: volume II: Categorical and Multivariate Methods.

23. Hussain M, Ahmed SM, Abderrahman W (2008) Cluster analysis and quality assessment of logged water at an irrigation project, eastern Saudi Arabia. Journal of Environmental Management 86: 297-307.

24. Chen K, Jiao JJ, Huang J, Huang R (2007) Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China. Environmental Pollution 147: 771-780.

25. WHO (2011) Guidelines for drinking water quality, 4th edn. WHO press P: 564.

26. Chutia J, Sarma S (2009) Seasonal variation of drinking water quality with respect to fluoride & nitrate in Dhakuakhana sub-division of Lakhimpur District of Assam. Int J Chem Sci 7: 1821-1830.

27. Ho KC, Chow YL, Yau JTS (2003) Chemical and microbiological qualities of the East River (Dongjiang) water, with particular reference to drinking water supply in Hong Kong. Chemosphere 52: 1441-1450.

28. Hujare MS (2008) Seasonal variation of physico-chemical parameters in the perennial tank of Talsande. Maharashtra Ecotoxicol Environ Monit 18: 233-242.

29. Armugan K, Elangovan K (2009) Hydrochemical characteristics and groundwater quality assessment in Tirupur Region, Coimbatore District, Tamil Nadu, India. Environ Geol 58: 1509-1520.

30. Goyal SK, Chaudhary BS, Singh O, Sethi GK, Thakur PK (2010) GIS based spatial distribution mapping and suitability evaluation of groundwater quality for domestic and agricultural purpose in Kaithal district, Haryana state, India. Environmental Earth Sciences 61: 1587-1597.

31. Ketata M, Bouhlila R, Gueddari M (2011) Suitability assessment of shallow and deep groundwaters for drinking and irrigation use in the El Khairat aquifer (Enfidha, Tunisian Sahel). Environ Earth Sci 65: 313-330.

32. Central Public Health and Environmental Engineering Organization (CPHEEO) (1998) A manual on water supply and treatment. Akalank Publication, New Delhi.

33. Blais JF, Tyagi RD, Aucleir JC (1993) Bio-leaching of metals and sewage sludge: effect of temperature. Water Resource. 27: 110-120.

34. Central Ground Water Board (CGWB) (2004) Annual report and other related reports on ground water quality, Central Ground Water Board, New Delhi.

35. Gajendra C, Thamarai P (2008) Study on statistical relationship between ground water quality parameters in Namibiyar river basin, Tamil Nadu, India, Pollution Research 27: 679-683.

36. WHO (1996) Guidelines for drinking water quality. World Health Organization, Geneva 1: 188.

37. Begum A, Krishna HS, Khan I (2009) Analysis of heavy metals in water, sediments and fish samples of Madivala lakes of Bangalore, Karnataka. International Journal of Chem Tech Res 1: 245-249.

38. ISO (1991) Industrial Tyres and Rims-cylindrical and Conical Base Rubber Solid Tyres (Metric Series)-designation, Dimensions and Marketing.

39. Ayers RS, Westcot DW (1985) Water quality for agriculture FAO irrigation and drain. 29: 1-109.

40. Nishanthiny SC, Thushyanthy M, Barathithasan T, Saravanan S (2010) Irrigation water quality based on hydrochemical analysis, Jaffna, Sri Lanka. American-Eurasian Journal of Agricultural &Environmental Science 7: 100-102.

41. Al-Bassam AM, Al-Rumikhani YA (2003) Integrated hydrochemical method of water quality assessment for irrigation in arid areas: application to the Jilh aquifer, Saudi Arabia. Journal of African Earth Sciences 36: 345-356.

42. Richards LA (1954) Diagnosis and Improvement of Saline and Alkali Soils Agric Handbook 60. New Delhi, India, pp: 98-99.

43. World Wide Fund (WWF) (2007) A special report on Pakistan waters at risk: water and health related issues in Pakistan and key recommendations, pp: 1-25.

44. American Water Works Association and Water Environment Federation (1995) Standard Methods for the Examinations of Water and Wastewaters, (19^{th} edn.), American Public Health Association. Washington.

45. Radojevic M, Bashkin VN (1999) Practical environmental analysis. Royal Society of Chemistry.

46. Trivedy RK, Goel PK (1986) Chemical and biochemical methods for water pollution studies. Environmental Publication, Maharashtra.

47. American Public Health Association (2000) Standard methods for the examination of water and wastewater. USA.

48. WHO (2008) Guidelines for drinking-water quality. World Health Organization, Geneva.

49. PSQCA (2004) Pakistan standards specification of bottled drinking water, under compulsory certification marks scheme. Pakistan Standards and Quality Control Authority, Ministry of Science and Technology. Pakistan.

50. Pakistan Council of Research in Water Resources (PCRWR) (2005) Water Quality Status. Pakistan.

51. Diersing, Nancy (2009) Water quality: Frequently asked questions. PDA. NOAA.

52. Kumar M, Kumari K, Ramanathan AL, Saxena R (2007) A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. Env Geol 53: 553-574.

53. Dahiya S, Kaur A (1999) Physico chemical characteristics of underground water in rural areas of Tosham subdivisions, Bhiwani district, Haryana. J Environ Poll 6: 281.

54. Balakrishnan P, Saleem A, Mallikarjun N (2011) Groundwater quality mapping using Geographic Information System (GIS): A case study of Gulbarga City,

Karnataka, India. Afr J Environ Sci Technol 5: 1069-1084.

55. Hari Haran A, varshya RC (2002) Evaluation of drinking water quality at Jalaripeta village of Visakhapatnam district Andhra Pradesh. Nat Environ Pollut Technol.
56. Joseph K (2004) A cleaner production approach for minimization of total dissolved solid in reactive dying effluents. Centre for Environmental Studies, Anna University, Chennai.
57. Sohani D, Pande S, Srivastava V (2001) Ground water quality at Tribal Town: Nandurbar (Maha rashtra). Indian J Environ Ecoplan 5: 475-479.
58. Subba RN (1998) Groundwater quality in crystalline terrain of Guntur district andhra Pradesh. Visakha Sci J 2: 51-54.
59. WHO (World Health Organization) (1996a) Guidelines for drinking water quality, (2nd edn.), Health Criteria and Other Supporting Information, Switzerland.
60. Sawyer CN, McCarty PL, Parkin GF (1994) Chemistry for environmental engineering, (4th edn.), McGraw-Hill, Singapore.
61. Tatawat RK, Chandel CPS (2007) Quality of ground water of Jaipur city, Rajasthan (India) and its suitability for domestic and irrigation purposes. Applied Ecology and Environment Research 6: 79-88.
62. Raghunath IM (1987) Groundwater, (2nd edn.), New Delhi, India.
63. Sawyer GN, McMcartly DL (1967) Chemistry of sanitary engineers, (2nd edn.), McGraw Hill, New York, p: 518.
64. Canter IW, Knox RC (1985) Septic Effects on Ground Water Quality Michigan. Lewis Publishing Inc, p: 336.
65. Taylor EW (1958) The Examination of Water and Water Supplies. Soil Science, p: 226.
66. Drever JI (1988) The Geochemistry of Natural Water Englewood Cliffs. Prentice Hall, New Jersey, pp: 383-390.
67. Jameel AA, Sirajudeen J (2006) Risk Assessment of Physico-Chemical Contaminants in Groundwater of Pettavaithalai Area, Tiruchirappalli, Tamil Nadu- India. Environmental Monitoring and Assessment 123: 299-312.
68. Raihan F, Alam JB (2008) Assessment of Groundwater Quality in Sunamganj of Bangladesh. Iranian Journal of Environmental Health Science and Engineering 5: 155-166.
69. Gupta DP, Sunita SJP, Saharan JP (2009) Physiochemical Analysis of Ground Water of Selected Area of Kaithal City (Haryana) India. Researcher 1: 1-5.
70. Richards LD (1964) Notes on water quality in Agriculture, Published as a water science and Engineering. Department of water science and engineering, University of California.
71. Kelly WP (1963) Use of saline irrigation water. Soil Sci 95: 355-391.
72. Biswas SN, Mohabey H, Malik ML (2002) Assessment of the Irrigation Water Quality of River Ganga In Haridwar District. Asian J Chem.
73. Joshi DM, Kumar A, Agrawal N (2009) Assessment of the irrigation water quality of River Ganga in Haridwar District India. Rasayan J Chem 2: 285-292.
74. Wilcox LV (1955) Classification and Use of irrigation Waters. United States Department of Agriculture, p: 969.
75. Gupta SK, Gupta IC (1987) Management of Saline Soils and Water. Oxford and IBH Publication Coy. New Delhi, India, p: 399.
76. Eaton FM (1950) Significance of carbonate in irrigation water. Soil Sciences 69: 123-134.
77. Catroll D (1962) Rain water as a chemical agent of geological process: a view. USGS Water Supply 1533: 18-20.
78. Freeze RA, Cherry JA (1979) Groundwater. Prentice-Hall, Englewood Cliffs.
79. Robinove CJ, Longfort RH, Brooks JW (1958) Saline water resources of North Dakota, US Geol. Surv Water Supply Paper 1428. P: 72.
80. Stuyfzand PJ (1989) Nonpoint source of trace element in potable ground water in Netherland. In: Proceeding of the 18th TWSA Water Working, Testing and Research Institute, KIWA, Nieuwegein, the Netherlands.
81. Usharani K, Umarani K, Ayyasamy PM (2010) Physico-Chemical and Bacteriological Characteristics of Noyyal River and Ground Water Quality of Perur, India. Journal of Applied Science and Environmental Management 14: 29-35.
82. Srivastava SK, Ramanathan AL (2008) Geochemical assessment of ground water quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. Environ Geology 53: 1509-1528.
83. Giridharan L, Venugopal T, Jayaprakash M (2008) Evaluation of the seasonal variation on the geochemical parameters and quality assessment of the groundwater in the proximity of River Cooum, Chennai, India. Environ Monit Assess 143: 161-178.
84. Yousef AF, Saleem AA, Baraka AM, Aglan O Sh (2009) The impact of geological setting on the groundwater occurrences in some Wadies in Shalatein-Abu Ramad area, SE desert, Egypt. European Water 26: 53-68.
85. Piper AM (1944) A graphic procedure in the geochemical interpretation of water analysis. American Geophysical Union Transactions 25: 914-923.
86. Zhang P (2013) EAS 44600 Groundwater Hydrology.
87. Durov SA (1948) Natural waters sand graphic representation of their composition. Dok, pp: 87-90.
88. Schoeller H, Konoplyantsev AA, Ineson J (1967) Geochemistry of ground water. An international guide for research and practice, UNESCO 15: 1-18.
89. Stiff HA (1951) The interpretation of chemical water analysis by means of patterns. Journal of Petroleum Technology 10: 15-17.
90. Bartram J, Ballance R (1996b) Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. United Nations Environment Programme and the World Health Organization.